DEVELOPMENT OF LOW BTU GAS BURNER FOR INDUSTRIAL APPLICATION

PHASE III

SR - 236B

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FINAL REPORT

BY

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SUMMARY

The Canadian Gas Research Institute has designed and constructed a 300 kW (1,000,000 Btu/h) burner for low energy gas. The burner was field tested at the site of a wood gasifier. The work was done under contract to the Department of Energy, Mines and Resources.

The burner was tested with both cleaned and "dirty" low energy gas. The firing rate was varied from 150 to 300 kW. Flame properties were controlled by varying the ratio of primary to secondary air.

The burner proved suitable for gases with heating values from 3 to 6 MJ/m^3 (80 to 160 Btu/ft^3). It also proved suitable for use with "dirty" gas.

The important parameters for scaling up the burner design were determined. Recommendations are made for various factors in burner construction.

1. INTRODUCTION

In Phase I of the project, a literature search was done to gather information on low energy gas. A burner rated at 3 kW was developed. Several concepts relating to flame stability and control of flame properties resulted (Reference 1).

Phase II involved the design of a 30 kW burner. This was built and tested in the CGRI laboratory. Low energy gas was simulated using compressed gas cylinders for the fuel components and oxygen-free combustion products for the inert components. The performance of the burner was measured for a range of gas compositions and for various combustion parameters. The burner was found to be suitable for low energy gases with heating values from 3 to 6 MJ/m^3 (80 to 160 Btu/ft^3). Clean combustion was obtained. The flame length and shape could be adjusted by varying the ratio of primary to secondary combustion air (Reference 2).

The objectives of Phase III were:

- to build a 300 kW burner by scaling up the design with minor improvements;
- to ensure that the burner could be turned down to 150 kW;
- to test the burner in the field at a gasifier site;
- to test the burner with "dirty" gas (uncleaned, direct from the gasifier).
- to determine the important parameters for scaling up the burner design.

2. DEVELOPMENT OF LOW ENERGY GAS BURNER

2.1 BURNER CONSTRUCTION

In the third phase of this project, the burner was scaled up from the firing rate of 29 kW of Phase II to a firing rate of 290 kW. The phase III burner design was basically the same as the Phase II burner, again using two-stage mixing to control flame size and shape (Reference 2). Schematic and pictorial drawings of the burner are shown in Figures 1 and 2.

The venturi was manufactured from sheet metal and fitted inside the inner pipe of the burner, as shown in Figure 1. This method of fitting the venturi led to a physically stronger burner assembly than the Phase II burner and allowed a relative reduction in overall burner assembly length.

Primary air entering the venturi via an orifice caused pressure reduction at the low energy gas inlet, allowing for reduced gas supply pressure. The primary air/gas mixture passed through the venturi and was distributed into the mixing chamber via sixteen ports, each of 21 mm diameter, over a 124 mm length of the inner pipe. Secondary air was introduced by means of a single pipe which was attached tangentially to the mixing chamber so as to set up swirl. A simple swirler plate (Figure 3) was located in the mixing chamber just upstream of the primary ports. The swirler plate was made from sheet metal and consisted of 24 fixed vanes set at an angle of 25^{o}. The swirler plate was designed to stabilize the swirl in the mixing chamber, resulting in better air/gas mixing and stable combustion. This swirler plate was preferred over a number of other swirler plates having different numbers of vanes and/or vane angle settings.

In order to compare the performance of the various swirler plates, each plate was in turn installed in the burner assembly. Air was blown into the secondary air inlet of the burner via the secondary air orifice measuring assembly. The static pressure

upstream of the swirler plate was monitored. The rotational velocity of the swirling air at the exit from the burner mixing chamber was used to classify the degree of swirl produced. The rotational velocity of the swirling air was measured by means of two quarter inch diameter plastic spheres extended radially on thin threaded rods from a shaft running in miniature low friction bearings. The centre-line of the shaft coincided with the swirler plate and mixing chamber centre-line. The length of the thin radial rods were adjusted so that the spheres were located in the annular jet emerging from the mixing chamber, thereby causing the whole assembly to rotate with the jet. The rotational frequency was monitored by a stroboscope. The basic designs of the sheet metal swirler plates tested and the method of swirl measurement employed were based on experience gained in an earlier CGRI research project (Reference 3).

The swirler plate and vane angle setting selected gave the best combination of high swirl with low pressure drop.

As in the Phase II burner, the mixing chamber and inner pipe of the new burner were made from standard pipe sizes. The mixing chamber was made up from a length of schedule 40 standard black pipe of nominal size 127 mm. This pipe, together with the nominal 76 mm standard black schedule 40 inner pipe gave an annular space of cross sectional area 6701 square mm.

The combustion zone was enclosed by a ceramic cone. The cone reradiates to the ignition zone. Initially it was intended that the ceramic cone would be produced by the supplier of the castable ceramic material (Fiberfrax L.D.S.) from which it was manufactured. The supplier attempted to have the cone made on a potter's wheel but when this failed the cone was produced in the CGRI laboratory by hand moulding onto a metal plug. Two

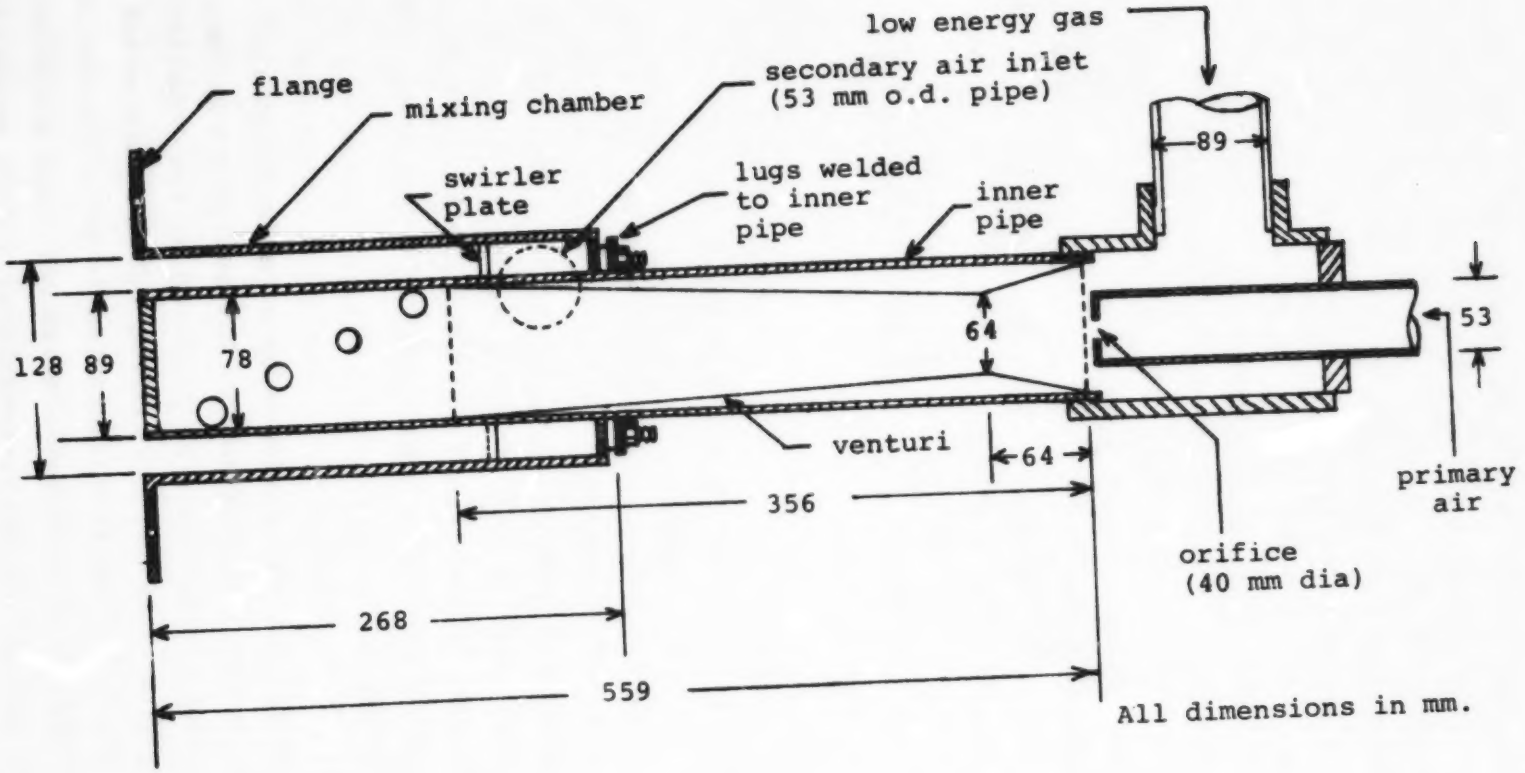


FIG.1 LOW ENERGY GAS BURNER

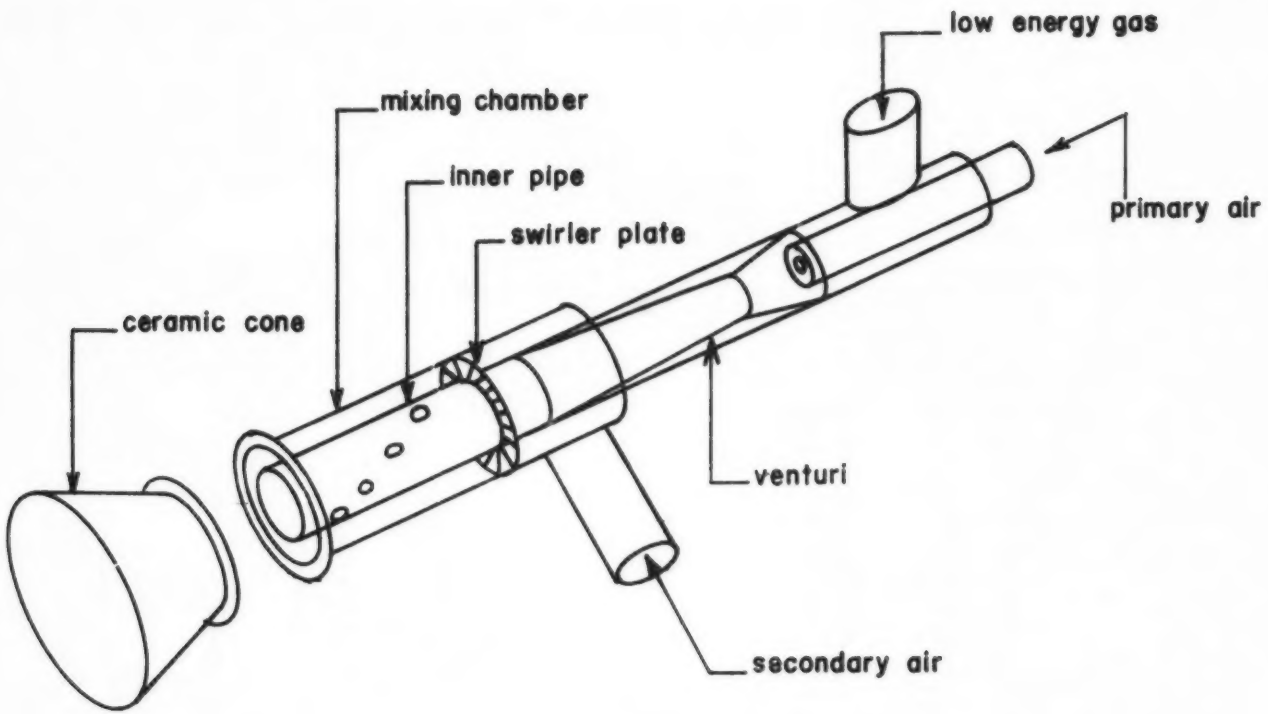
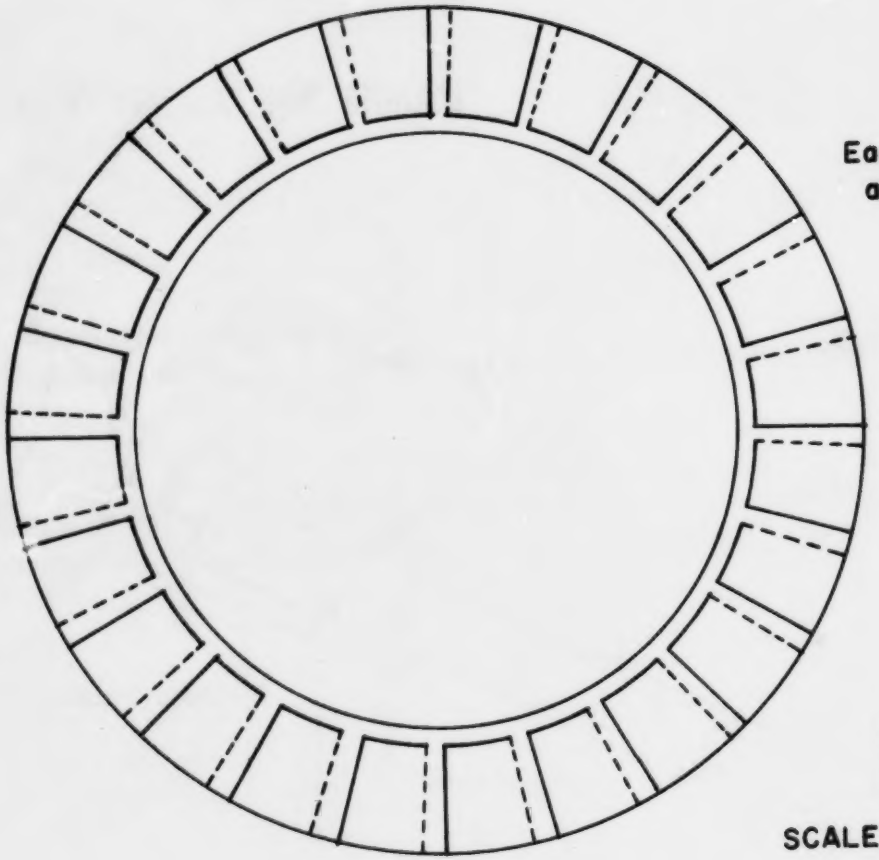


FIG. 2 LOW ENERGY GAS BURNER



Each vane folded at 25° angle to plane of this page

broken lines are folds

solid lines are cuts

SCALE = full size

FIG. 3 24 VANE SHEET METAL SWIRLER PLATE

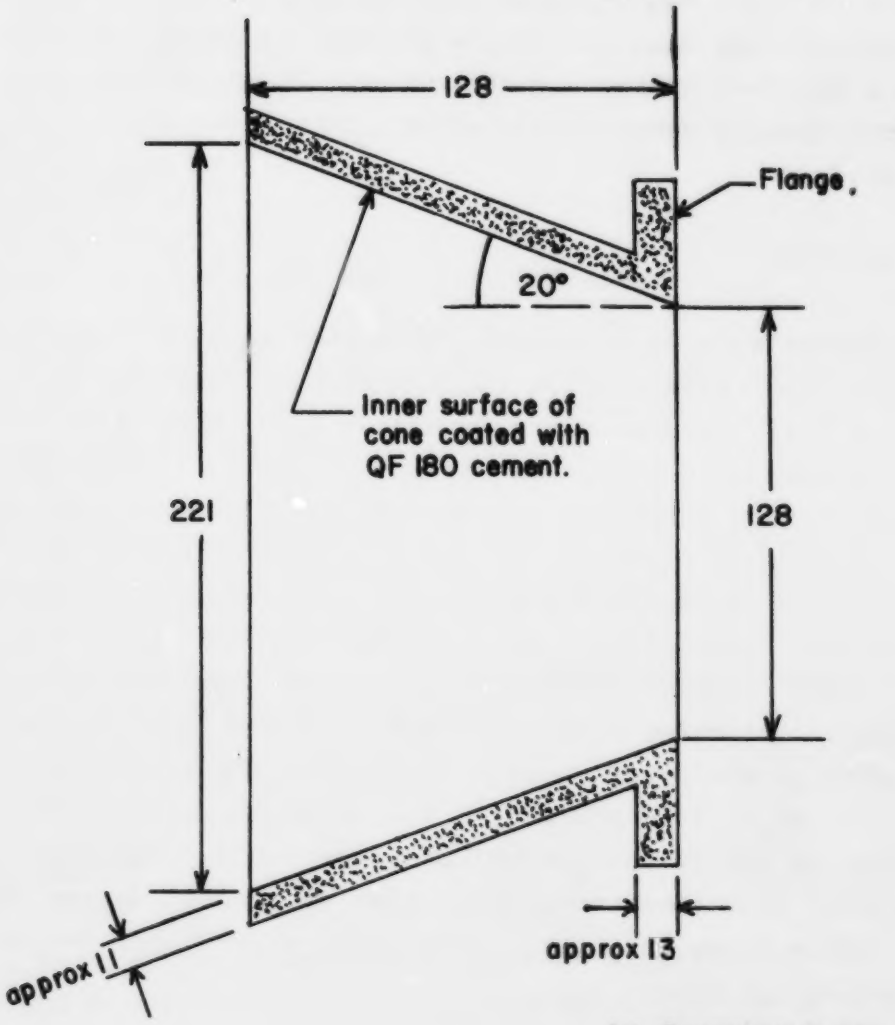


FIG. 4 MOULDED CERAMIC BURNER CONE

identical cones were made as shown in Figure 4. The cones were flanged so that they could be easily attached to the flanged mixing chamber of the burner. The ceramic cones were given a coating of QF180 cement which offered greater resistance to high temperature erosion of the ceramic material and produced a smoother surface on the cones. It was also expected that the coating cement would afford better resistance to moisture.

2.2 WOOD GASIFIER

Arrangements were made to test the burner in Saskatchewan. The wood gasifier (Figure 5) is located at the Saskatchewan Forest Products Corp. plywood plant in Hudson Bay. Wood chips are a waste product from the plant and are currently incinerated. The gasifier is owned and operated by Saskatchewan Power Corp.

The gasifier is of the updraft type. The gas direct from the gasifier, or "dirty" gas, has a higher heating value (HHV) up to 3.7 MJ/m^3 (100 Btu/ft^3). This does not take the tar into account. A cleaning system is used to remove most of the tar, particulates and water vapor. The HHV of the "clean" gas ranges up to 5.6 MJ/m^3 (150 Btu/ft^3). The large increase in HHV after cleaning is due to the removal of water vapor. The wood can contain up to 50% moisture after rain has fallen on the chip pile. This leads to a relatively large water vapor content in the low energy gas.

A flare is used to dispose of the gas while the gasifier is being warmed up. The gas starts out below the flammable limit with high concentrations of oxygen and nitrogen. The concentrations of the flammable components gradually increase and finally attain steady values. This gasifier takes about 3h from a "cold" start (20^{o}C ambient temp.) to steady state. Typical steady state values are shown in Table 1.

Saskatchewan Power has tested a nozzle mix burner on their low energy gas. Satisfactory combustion was obtained using "clean" gas. The burner was not suitable for "dirty" gas. Most of the Saskatchewan Power work on low energy gas has concentrated on the generation of electricity using internal combustion engines. A modified diesel engine coupled to a generator is used in Hudson Bay.

TABLE 1 - TYPICAL LOW ENERGY GAS COMPOSITIONS (%)

	H_2	CO	CH_4	CO_2	N_2	O_2	H_2O	HHV (MJ/m^3)
"clean"	12.4	25.8	2.3	8.6	45.9	1.0	4.0 (Note 1)	5.43
"dirty"	7.4	18.2	1.4	4.7	35.1	0.7	32.5 (Note 2)	3.59

Notes 1) estimated by assuming saturated gas at the cleaning system exit temperature

2) measured

2.3 EQUIPMENT

The burner and gasifier were connected by flexible steel hoses. Combustion air for the burner was supplied by a high pressure blower powered by a 550 volt three phase electric motor. As it was known in advance that the power supply available on site would be 480 volt, the blower was tested at the lower supply voltage in the CGRI laboratory prior to shipment to the test site. The blower was found capable of fulfilling the air requirements at the lower voltage.

In order to measure the combustion airflows during field testing, orifice assemblies were made up for primary and

secondary air supplies as well as for the low energy gas supply. The orifice assemblies were calibrated in the CGRI laboratory against accurate dry gas meters. The procedure for setting the gas orifice is given in Appendix A.

The orifice assemblies, which were made up from standard black pipe, were mounted together with the combustion air blower and the burner on a portable cart of approximate dimensions 1.2 m cube. Manometers for measuring pressure drops across the orifice assemblies and magnehelic gauges for measuring gas and air supply pressures were attached to the cart which was shipped as a self contained unit to the site of the wood gasifier. The cart is shown in Figure 5.

As there was no readily available instrumentation capable of measuring the moisture content of the low energy gas produced by the wood gasifier, a method of measurement was devised. A vacuum pump was used to draw a continuous sample of the low energy gas through an aluminum cylinder of known volume which had been pre-heated to a temperature higher than the dew point temperature of the gas. After passing gas through the cylinder for a length of time sufficient to stabilize the temperature of the gas inside the cylinder and the cylinder walls (measured with thermocouples), the cylinder was sealed and immersed in a cold water bath until the temperature of the gas inside the cylinder stabilized at a temperature much below its dew point temperature. A vacuum gauge, which was permanently attached to the cylinder was used to measure the vacuum created in the cylinder as the water vapour in the gas condensed on cooling. Knowing the volume of the trapped gas and from the temperature and pressure measurements, it was then possible to calculate the moisture content of the low energy gas. The measurement procedure is given in Appendix B.

2.4 TESTS IN THE CGRI LAB

Burner components were tested individually during assembly.

The method of swirling the secondary air was optimized. Flow straighteners were added to the orifice sections to make the flow measurement independent of end effects.

After the burner was completed it was tested using diluted natural gas. The gas was diluted using 100% excess air. This did not allow a realistic simulation of low heating value; however, it was found that further dilution gave an unrealistic flame. The burner was successfully operated at various firing rates from 150 to 300 kW. The tests were of limited duration because the burner cone temperature was above the limit for the refractory. This was indicated by the presence of a characteristic odour, first identified in Phase II (Reference 2).

Based on these tests, modifications were made to improve flame stability. Shims were installed to move the mixing chamber relative to the inner pipe. This gave a sharp transition in the gas/air path at the entrance to the cone. The cone was recoated with QF180 cement.

At the conclusion of these tests, all equipment was packed, crated and shipped to Hudson Bay.

2.5 TESTS WITH "CLEAN" LOW ENERGY GAS

2.5.1 IGNITION

The burner ignited very easily with "clean" gas. A small domestic propane torch and a flint sparker (normally used for an oxyacetylene welding torch) were both used to ignite the low energy gas burner. The burner was ignited when either device was placed outside the cone, in the flow path of the mixture.

2.5.2 FLAME STABILITY

The burner was tested at various firing rates from 146 to 293 kW. Based on the work in Phase II, the excess air level was set at 10% (Reference 2). Three characteristic combustion air settings were used at each firing rate:

- 25% primary air/ 75% secondary air
- 50% primary/ 50% secondary
- 75% primary/ 25% secondary

A stable blue flame was obtained at each firing rate. At rates of 190 kW or less, primary air must be limited to 50% or less to prevent flashback into the burner mixing chamber. As in Phase II, the flame did not enter the inner pipe when flashback did occur at "low" firing rate and "high" primary air (Reference 2).

2.5.3 FLAME SHAPE

The flame shape could be adjusted by varying the ratio of primary to secondary combustion air. The flame shapes for the three characteristic air settings were similar to the Phase II burner (Reference 2). The results are shown in Figures 6, 7 and 8 while firing the burner at 244 kW on "dirty" gas. The high water vapor content gave a luminous orange flame, which gave better photographs than with "clean" gas. Movies were also taken during these tests. The flame shapes with "clean" gas were similar.

2.5.4 PRESSURES REQUIRED

Static pressures were measured for low energy gas, primary air and secondary air. Each measuring station was at the burner, downstream of the orifice sections. The results for various firing rates are shown in Table 2.

FIGURE 5 - WOOD GASIFIER AND BURNER CART

FIGURE 6 - FLAME SHAPE WITH 25% PRIMARY AIR

FIGURE 7 - FLAME SHAPE WITH 50% PRIMARY AIR

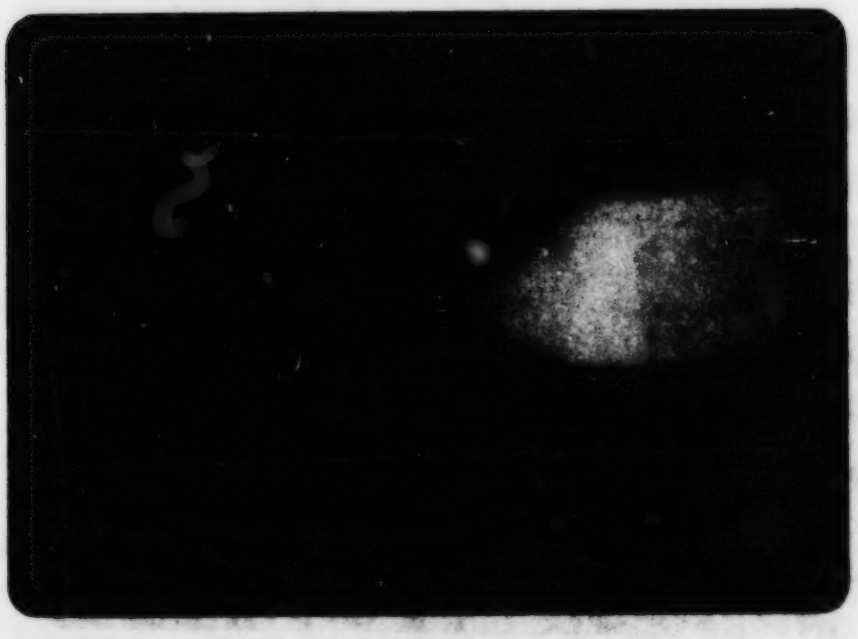


FIGURE 8 - FLAME SHAPE WITH 75% PRIMARY AIR

TABLE 2 - CLEAN GAS TESTS

FIRING RATE (kW)	COMBUSTION AIR SPLIT PRIM / SEC	GAUGE PRESSURE (Pa) GAS	PRIM	SEC	ESTIMATED FLAME LENGTH (m)
293	25/75	1020	1270	1170	0.7
293	50/50	1100	2070	720	0.9
293	61/39	1120	2440	620	0.9
256	25/75	600	820	900	0.7
256	50/50	720	1440	600	0.9
256	75/25	700	2320	500	0.8
220	25/75	450	620	670	-
220	50/50	550	1070	470	-
220	75/25	470	1720	370	-
183	25/75	400	550	500	-
183	50/50	400	800	350	-
146	25/75	200	250	300	0.4
146	50/50	220	500	220	-

2.5.5 MISCELLANEOUS

Flame lengths were estimated during some of the "clean" gas tests. These are shown in Table 2. The figures have limited accuracy because the burner was pointing into the prevailing wind at the site.

A comparison with similar data (Reference 2) for the 30 kW burner showed that scaling up the burner by a factor of 10 increased the flame length by a factor of 4.

Small amounts of tar and condensate were present in the "clean" gas. The tar was completely burned and the water was completely evaporated by the flame. During commissioning of the gasifier/ burner combination however, low energy gas was passed through the burner for a total of several hours without igniting the burner. This caused a thin deposit of tar on the cone, which hardened overnight. This deposit required several hours of burner operation to be burnt off. It caused minor adverse effects on the flame while burning off.

2.6 TESTS WITH "DIRTY" LOW ENERGY GAS

2.6.1 IGNITION

The burner was much more difficult to ignite with "dirty" gas. The flint sparker had no effect and the small propane torch was blown out. A burning rag soaked in Number 2 fuel oil was used successfully. This worked best when it was moved into the cone on the burner centreline, just downstream of the inner pipe. This was in the bluff body recirculation zone. This confirms the finding in Phase II that this is the best location for the ignition source (Reference 2).

A large industrial hand-held propane torch was also used. The burner was ignited when the torch was held at the cone exit, pointing into the cone.

2.6.2 FLAME STABILITY

The burner was fired on "dirty" gas at various rates from 192 to 255 kW. A stable orange flame was obtained at each rate while using gas with the composition given in Table 1. Flame stability was sensitive to the excess air level. An increase in combustion air of about 10% (i.e. to about 20% excess air) moved the burner close to the blow off limit. The burner was insensitive to excess air level while firing clean gas. Increases in air flow of 50% did not decrease flame stability.

During subsequent testing at 234 kW, with slightly "leaner" gas, the burner was even more sensitive to excess air level. In this case the gas contained about 35% H_2O (estimated) and the HHV was 3.05 MJ/m^3. The burner only sustained combustion at 0% excess air (or 100% theoretical air). Small changes in combustion air flow caused blow off. This agrees well with the results in Phase II, where it was found that 3 MJ/m^3 was the lowest HHV that could be accommodated, using combustion air at "room" temperature (Reference 2).

Tar deposits which had hardened on the cone during shut downs caused minor detrimental effects on flame stability. After igniting the burner, the deposits formed into individual flaps, each about 25 x 25 x 2 mm. During the course of burning off, the flaps at the top of the cone sagged to leave a gap between flap and cone of about 5 mm. A small amount of the low energy gas escaped unburnt through these gaps. The flame was disturbed slightly in the immediate vicinity of the tar flaps. After firing the burner for 2h the flaps had broken off and were blown out of the burner.

2.6.3 BEHAVIOUR OF TAR IN THE BURNER

Tar and condensate were present in the burner during all tests. With "clean" gas, the tar was completely burned and the water was evaporated by the flame. With "dirty" gas, a large fraction of the tar was ejected from the burner in the form of liquid droplets. After the burner cone had warmed up, the tar droplets were burning as they fell from the burner. Eventually the puddle formed by the tar on the ground below the burner was also ignited by burning droplets. The tar flow was estimated at 10 ℓ/h. Provision might have to be made for tar when designing a combustion chamber for the burner.

Of the remaining fraction of the tar input to the burner, some of it burned inside the burner and some of it was deposited in the cone during the early stages of testing. The burning tar was indicated by a yellow flame (the low energy gas flame was orange). This was concentrated at the bottom of the cone. The burning tar tended to increase flame stability.

Tar deposits formed only on the burner cone during testing from 192 to 255 kW. All gas and air passages upstream of the cone had a surface coating of tar, about 1 mm thick, with no tendency towards blockage. The tar on the cone built up gradually after ignition. The maximum deposit occurred about

15 min after ignition and was 10 mm deep on the bottom surface of the cone (2 mm deep on higher surfaces). After this, the deposit gradually burned off over a period of several hours.

These tests were complicated by the presence of hardened tar on the cone (see previous section). To verify burner performance with "dirty" gas, the fresh cone was mounted and the burner was fired at 282 kW. Again, the maximum deposit occurred after 15 min and had a similar thickness. After 3h of burner operation, about half of the deposit had burned off.

Parts of the deposit at the bottom of the cone had a glassy appearance, possibly due to small quantities of fused sand. It was known that sand entered the gasifier via the wood chip pile. The deposits in the cone also had reddish-brown areas, possibly rust from the piping system. These substances did not stick to the cone themselves but were held by the tar which made up most of the deposit. The tar had a dark black appearance and a sticky consistency.

2.7 SCALE UP PARAMETERS

2.7.1 DESIGN PROCEDURE

Burner design can be described by the flow velocities of the low energy gas/combustion air mixture through the various parts of the burner. The following steps can be used to scale up the burner.

1. Determine the composition of low energy gas for which the burner will be used.

2. Calculate the heating value and the ratio of gas flow to combustion air flow (at 10% excess air).

3. Choose the design firing rate. If the burner must be capable of turn down, then the design firing rate must be lower

than the maximum rate. If the design rate is too low, then excessive gas and air pressures will be required at the maximum rate. If the design rate is too high, then the flame may flash back into the mixing chamber at the minimum rate with "high" primary to secondary air ratio.

4. Size the venturi throat for a gas/primary air velocity of between 20 and 30 m/S (at the minimum and maximum primary air flows respectively) at the design firing rate.

5. Size the venturi diffuser for a length of 5 to 6 throat diameters with a half angle of 1½ to 2°. This determines the diameter of the inner pipe.

6. Size the port diameter and choose the number of ports, such that the gas/primary air velocity is not less than 6 m/S at the minimum firing rate and minimum primary air flow. There should be at least 16 ports in an evenly distributed pattern. The spacing between circumferential rows of ports should be 2 port diameters. The same space should be left beside each end row.

7. Size the secondary air pipe(s) such that the maximum secondary air velocity does not exceed 25 m/S at the maximum firing rate. If this results in a pipe diameter greater than half of the mixing chamber diameter, then multiple secondary air pipes should be used.

8. The lengths of the inner pipe and the mixing chamber can now be determined. If the venturi is built in to the inner pipe, then the total length can be reduced by overlapping the secondary air pipe(s) and part of the venturi diffuser.

9. Size the swirler plate such that the maximum tangential secondary air velocity does not exceed 35 m/S at the maximum firing rate.

10. Size the mixing chamber. The axial velocity of the gas/air mixture must not be less than 14 m/S at the design firing rate. The blockage ratio should be about 0.5 (ratios up to 0.66 are acceptable).

11. The mixing chamber diameter determines the cone entrance diameter. The cone is 1 entrance diameter long with a half angle of 20°. The wall thickness is determined by the refractory properties.

2.7.2 PROVISION FOR IGNITION

It was found that the best position for the ignition source was at the end of the inner pipe. In order to supply fuel to a pilot or electric current to spark electrodes (or both), a small diameter tube could be placed coaxially inside the inner pipe. The ignition source could be installed in the cap at the end of the inner pipe. Provision would have to be made for removal of the cap for maintenance. The small tube should penetrate the inner pipe just outside of the mixing chamber.

2.7.3 MATERIALS

Recommended materials for burner construction are shown in Table 3. Some components can be made from standard pipe sizes for ease of construction and durability.

TABLE 3 - RECOMMENDED MATERIALS FOR BURNER CONSTRUCTION

COMPONENT	MATERIAL	REMARKS
Venturi	Galvanized Steel	20 gauge sheet
Inner pipe	Carbon Steel	Standard pipe
Mixing chamber	Carbon Steel	Standard pipe
Secondary air pipe	Carbon Steel	Standard pipe
Swirler plate	Galvanized Steel	20 gauge sheet
Mixing chamber flange	Mild Steel	1.6 mm plate (1/16")
Split ring burner cone retainer	Mild Steel	1.6 mm plate
Burner cone	Fiberfrax LDS	Coating of QF180 cement

3. CONCLUSIONS

1. The scaled up burner performed as expected from the earlier work.

2. The burner proved suitable for low energy gases with heating values from 3 to 6 MJ/m^3.

3. The burner proved suitable for firing rates from 150 to 300 kW.

4. Flame properties were controlled by varying the ratio of primary to secondary air.

5. The burner proved suitable for "dirty" gas.

6. Accurate setting of combustion air flows is essential with "dirty" gas.

7. Provision may have to be made for tar when designing a combustion chamber for the burner.

4. RECOMMENDATIONS

1. Use the data on gas/air velocities through the burner when scaling up the design above 300 kW.

2. Use the materials in Table 3 for burner construction.

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Appendix A

CALCULATION OF LOW ENERGY GAS FLOW

The orifice sections for low energy gas, primary air and secondary air were designed in accordance with the ASME Power Test Codes, as given in Reference 4. The gas orifice was tested with air in the CGRI lab to produce a graph of flow coefficient versus Reynolds number (Figure A1).

At the gasifier site, the following procedure was used to set the flow of low energy gas:

1. Choose firing rate F
2. From the measured gas composition, calculate the specific gravity S and the heating value HHV.
3. Find the low energy gas flow Q required from
$$Q = \frac{F}{HHV}$$
4. Measure the low energy gas temperature T and pressure P.
5. Find the gas viscosity μ from Reference 5.
6. Find the Reynolds number from
$$Re = C_1 \frac{SQ}{\mu}$$
where C_1 = a constant
7. Find the orifice flow coefficient K from Figure A1.
8. Set the orifice pressure drop ΔP at
$$\Delta P = C_2 S \frac{P}{T} \left(\frac{Q}{K}\right)^2$$
where C_2 = a constant.

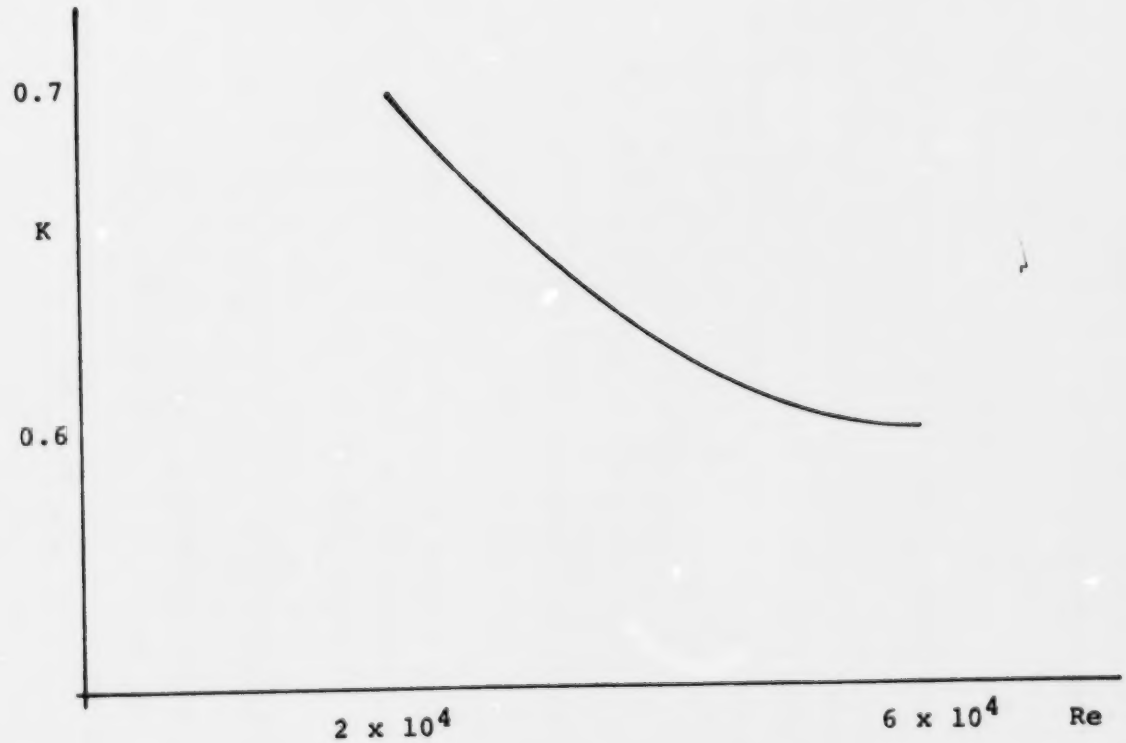

FIG. AI GAS ORIFICE FLOW COEFFICIENT

Appendix B

MEASUREMENT OF WATER VAPOR CONTENT

The two steps in water vapor measurement are shown in Figure B1. During the sample mode, the low energy gas and cylinder temperature is stabilized at $T_1 > 100^{\circ}C$. The initial pressure P_1 is measured (P_1 is approximately 101 kPa). The total number of moles of gas plus water vapor is

$$N_1 = \frac{P_1 V}{RT_1}$$

where V is the cylinder volume and R is the gas constant.

After the cylinder is sealed and cooled in the water bath, P_2 and T_2 are measured (T_2 is approximately the ambient temperature). The number of moles of gas plus water vapor remaining is

$$N_2 = \frac{P_2 V}{RT_2}$$

The number of moles of condensed water is

$$N\ell = N_1 - N_2$$

With the gas and cylinder temperature stabilized at T_2, the gas will be saturated with the remaining water vapor. The number of moles of water vapour is

$$N_v = \frac{P_{sat}}{P_2} N_2$$

where P_{sat} is the saturation pressure at T_2, found from Reference 5. The fraction F of water vapor present in the initial sample is

$$F = \frac{N\ell + N_v}{N_1}$$

Using all of the above equations, it can be shown that

$$F = 1 - \left(1 - \frac{P_{sat}}{P_2}\right) \frac{P_2}{P_1} \frac{T_1}{T_2}$$

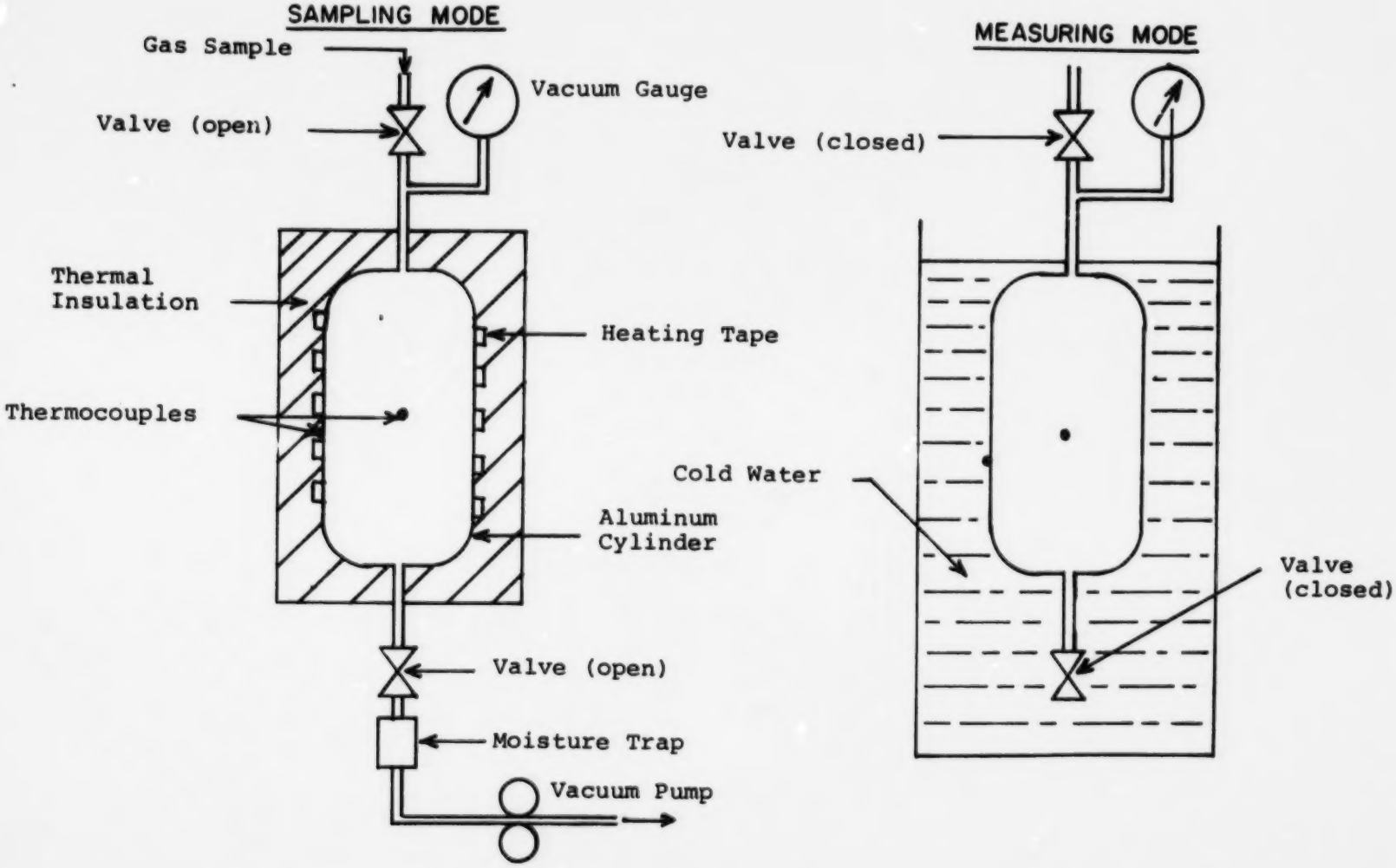

FIG. BI APPARATUS FOR DETERMINATION OF MOISTURE CONTENT IN LOW ENERGY GAS

POOR

QUALITY

ORIGINAL